

CHAPTER 64

Disorders of the Nerve Roots, Plexuses, and Peripheral Nerves

KEY TEACHING POINTS

- In patients with neck or arm pain, an asymmetric reduction of any deep tendon reflex in the arm increases the probability of cervical radiculopathy. The ability to fully rotate the neck (>60 degrees) decreases the probability of cervical radiculopathy.
- In patients with cervical radiculopathy, the most decisive findings indicating the level of injury are weak elbow flexion (C5), diminished biceps or brachioradialis reflex or loss of sensation in the thumb (C6), weak elbow extension or diminished triceps reflex (C7), and weak finger flexion or loss of sensation in the little finger (C8).
- In patients with suspected carpal tunnel syndrome, diminished sensation in the distribution of the median nerve or a square wrist ratio increases the probability of carpal tunnel syndrome (as defined by nerve conduction studies). An “unlikely” Katz hand diagram decreases probability.
- In patients with lower back and leg pain, the presence of ipsilateral calf wasting, weak ankle dorsiflexion, or a positive crossed straight leg raising maneuver all increase probability of lumbosacral radiculopathy.
- In patients with lumbosacral radiculopathy, the most decisive findings indicating the level of injury are diminished knee extension, diminished patellar reflex, or a positive femoral stretch test (L2 to L4); an asymmetric medial hamstring reflex or diminished sensation on the dorsum of the foot (L5); and ipsilateral calf wasting or a reduced Achilles reflex (S1).

I. INTRODUCTION

Nerve roots destined to innervate the limbs exit through vertebral foramina and intermingle in plexuses (i.e., the brachial and lumbosacral plexuses) before emerging as peripheral nerves that extend to the fingers and toes. Lesions anywhere along this pathway—from spinal nerve roots to the final peripheral nerve branch—produce combinations of pain, *lower motor neuron* weakness, and sensory loss.

A lesion in the nerve root is called a **radiculopathy**; one in the plexus, a **plexopathy**; and one in the peripheral nerve, a **peripheral neuropathy**. This chapter explains how to distinguish these lesions in patients with nerve complaints of the arms or legs. Because the neuroanatomy of these lesions is complex, accurate diagnosis requires systematic examination of all the limb’s muscles, sensations, and reflexes.

II. THE ARM

A. INTRODUCTION

In patients presenting with nerve complaints of the upper extremity, the most common neurologic diagnosis is carpal tunnel syndrome, followed by polyneuropathy, ulnar neuropathy, and cervical radiculopathy.¹⁻³ Other focal neuropathies and plexopathies are less common. Most cervical radiculopathies affect the C6 or C7 root.⁴⁻⁷

B. NEUROLOGIC FINDINGS

I. MOTOR

Most muscles of the arm are innervated by nerves from more than one spinal segment. Fig. 64.1 presents the relationship between the different peripheral nerves (grouped in rows) and their corresponding spinal roots (in columns). The spinal levels listed in Fig. 64.1 are based on several lines of evidence, including Bolk's detailed dissection of a single human subject,^{8,9} electrodiagnostic studies,^{10,11} and bedside observations of patients with documented spinal root lesions.^{5,12}

SPINAL SEGMENTS	C5	C6	C7	C8	T1
Proximal nerves					
Rhomboids (dorsal scapular nerve)	Dark blue				
Supraspinatus (suprascapular nerve)	Dark blue				
Infraspinatus (suprascapular nerve)	Dark blue				
Deltoid (axillary nerve)	Dark blue	Light blue			
Serratus anterior (long thoracic nerve)	Light blue		Dark blue		
Musculocutaneous nerve					
Biceps	Dark blue	Dark blue			
Radial nerve					
Triceps			Dark blue	Dark blue	
Brachioradialis	Dark blue	Dark blue	Dark blue		
Extensor carpi radialis longus	Dark blue	Dark blue	Dark blue		
Extensor carpi ulnaris	Dark blue	Dark blue	Dark blue	Light blue	
Finger extensors		Dark blue	Dark blue	Light blue	
Median nerve					
Pronator teres			Dark blue	Dark blue	
Flexor carpi radialis			Dark blue	Dark blue	
Flexor digitorum superficialis			Light blue	Dark blue	
Abductor pollicis brevis			Light blue	Dark blue	
Ulnar nerve					
Flexor carpi ulnaris			Light blue	Dark blue	
Hypothenar muscles			Light blue	Dark blue	
Interossei			Light blue	Dark blue	

FIG. 64.1 INNERVATION OF THE MUSCLES OF THE ARM. This figure indicates those spinal levels that usually (dark blue shade) and sometimes (light blue shade) contribute to the corresponding muscle; based on references 4, 5, and 8 to 14.

A. RADICULOPATHY

Even though most muscles receive innervation from more than one spinal nerve root, injury to one root is usually sufficient to cause a significant loss of power. The motor examination of radiculopathy has two characteristics: (1) Weakness affects two or more muscles from the same spinal segment but different peripheral nerves (i.e., all of the weak muscles are in the same *column* in Fig. 64.1). For example, a C6 radiculopathy may simultaneously weaken elbow flexion (biceps muscle, musculocutaneous nerve) and wrist extension (radial and ulnar wrist extensors, radial nerve).⁵ (2) Weakness may involve muscles innervated by *proximal nerves*, which are listed in the top rows of Fig. 64.1. Proximal nerves originate from the nerve roots but then promptly innervate muscles of the shoulder, thus moving away from the course of the peripheral nerves of the arm. Therefore if a muscle innervated by one of these nerves is weak in a patient with nerve complaints of the arm or hand, the lesion must be a proximal one near the nerve roots. A common example is the finding of scapular winging (i.e., weak serratus anterior muscle, long thoracic nerve) in a patient with arm pain and triceps weakness. Involvement of the serratus anterior points to the C7 root and away from the radial nerve or brachial plexus.¹³

B. BRACHIAL PLEXOPATHY

Lesions of the brachial plexus cause simultaneous weakness of muscles from two or more adjacent spinal segments (i.e., adjacent *columns* in Fig. 64.1) and from two or more peripheral nerves. Brachial plexus lesions usually affect either the upper plexus (C5 to C6) as a group, causing weakness of the shoulder and upper arm but sparing all muscles of the hand, or the lower plexus (C7 to T1) as a group, affecting all muscles of the hand but sparing those of the shoulder and upper arm.

C. PERIPHERAL NERVE DISORDERS

These lesions weaken two or more muscles from a *single* peripheral nerve (which may have different spinal segments) and spare muscles from other nerves. For example, a complete radial nerve injury weakens the brachioradialis muscle (C5-C6),* elbow extension (triceps, C7), wrist extension (wrist extensors, C6-C7), and finger extension (finger extensors, C8).

In Fig. 64.1, the muscles belonging to each peripheral nerve are listed in the order that their branches diverge from the main trunk. Therefore a proximal lesion of the radial nerve in the axilla would cause the findings described in the previous paragraph, but a lesion of the radial nerve at the elbow, after the branch to the brachioradialis muscle, spares the triceps and brachioradialis but weakens more distal muscles (i.e., wrist and finger extensors).

Some peripheral nerve lesions can be recognized at a glance, such as the wrist drop of radial neuropathy (Fig. 64.2) and the claw-hand appearance of ulnar neuropathy (Fig. 64.3). A callus over the hypothenar eminence in a patient with ulnar muscle weakness suggests damage to the deep branch of the ulnar nerve caused by chronic pressure on the heel of the hand from bicycling or using a walker.^{15,16}

2. SENSORY FINDINGS

Radiculopathy causes sensory loss in a dermatomal pattern (see Table 62.1 and Fig. 62.1 in Chapter 62). Brachial plexus lesions cause sensory loss from adjacent dermatomes. Peripheral nerve lesions cause the sensory loss described in Fig. 64.4.

*Testing elbow flexion with the forearm midway between supination and pronation reveals brachioradialis weakness.¹⁴

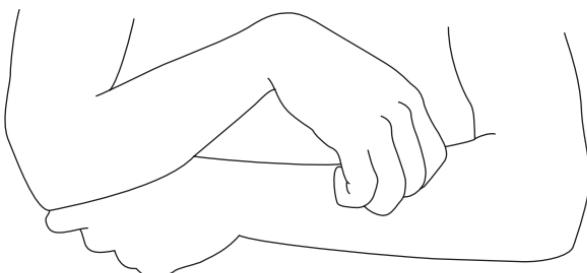


FIG. 64.2 WRIST DROP OF RADIAL NEUROPATHY. This patient has a right radial nerve palsy, thus cutting off the strength of the patient's wrist and finger extensors and causing the hand to droop downward from its own weight.

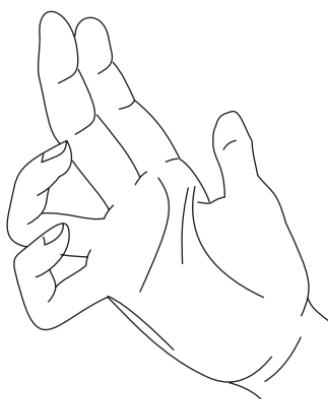


FIG. 64.3 CLAW HAND OF ULRNAR NERVE PALSY. All metacarpophalangeal joints are hyperextended because of paralysis of all interossei and unopposed action of finger extensors (radial nerve). The hyperextension is less prominent in the index and middle fingers because the lumbricals of these digits, innervated by the median nerve, act to flex the joint. Tethering from the flexor tendons causes all interphalangeal joints to flex.

One pure sensory syndrome of the arm is **cheiralgia paresthetica**, from injury to the superficial branch of the radial nerve, usually because of too tight a wristband or handcuffs. Sensory findings are confined to the radial aspect of the dorsal hand.¹⁷

3. REFLEXES

The three muscle stretch reflexes of the arm are the biceps (musculocutaneous nerve, C5-C6), brachioradialis (radial nerve, C5-C6), and triceps (radial nerve, C7-C8).[†] Therefore the finding of abnormal reflexes *excludes* both median and ulnar neuropathies (nerves lacking reflexes) and instead *increases* the probability of radiculopathy or plexopathy. Radial nerve lesions usually spare the brachioradialis and triceps reflexes because the branches to these muscles diverge from the main trunk proximally in the axilla, and most injuries to this nerve occur at a more distal point (e.g., humeral fracture, or **Saturday night palsy**).

[†]Even though weakness of the triceps may follow lesions in the C6 or C7 roots (C7 is most common; see Fig. 64.1), the absent triceps jerk usually results from C7 or C8 lesions.⁵

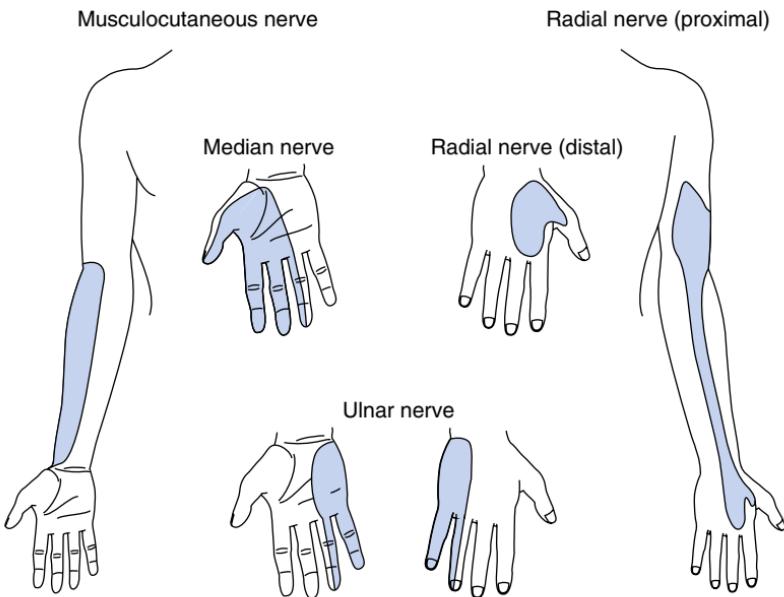


FIG. 64.4 SENSORY BRANCHES OF THE PERIPHERAL NERVES OF THE ARM. The three figures on the left depict the *volar* surface of the arm; the three on the right, the *dorsal* surface. Proximal lesions of the radial nerve (*upper right*), near the axilla (and above the origin of the posterior cutaneous nerves of the arm and forearm) affect sensation of the posterior arm, forearm, and hand; more distal lesions in the radial nerve (e.g., at the elbow) affect only the dorsal hand. Proximal lesions of the median nerve affect both palm and fingers; more distal ones (e.g., in the carpal tunnel) affect just the fingers. The sensory innervation of the medial arm and forearm derives from cutaneous nerves that branch directly off the brachial plexus.

4. PROVOCATIVE TESTS

One traditional test for cervical radiculopathy is the **Spurling test**, or **neck compression test**. In this test, the clinician turns and tilts the patient's head and neck toward the painful side and then adds a compressive force to the top of the head.¹⁸ Aggravation of pain is a positive response. The **Tinel sign** and **Phalen sign** are provocative tests traditionally used to diagnose carpal tunnel syndrome. (See the section titled “[Diagnosis of Carpal Tunnel Syndrome](#).”) The Katz hand diagram (for carpal tunnel syndrome) appears in [Fig. 64.5](#).

C. ADDITIONAL DIAGNOSTIC CLUES

I. THE CLAVICLE

The brachial plexus lies just behind the clavicle. Therefore additional physical findings in the supraclavicular space—such as mass, adenopathy, hemorrhage, or other evidence of trauma—suggest injury to the brachial plexus. Trauma *above* the clavicle injures roots; that *below* the clavicle injures peripheral nerves.

2. HORNER SYNDROME (SEE CHAPTER 21)

An associated Horner syndrome (i.e., ipsilateral small pupil and ptosis) indicates radiculopathy (C8-T1) or a lesion of the lower brachial plexus.

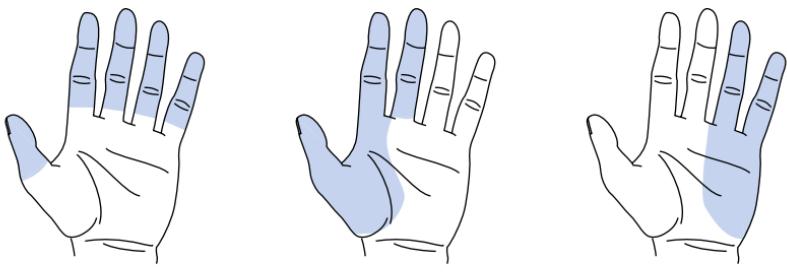


FIG. 64.5 KATZ HAND DIAGRAM. The Katz hand diagram is a self-administered diagram of the hand that depicts the patient's symptoms: the “classic” pattern (example, left) describes symptoms affecting at least two of digits 1, 2, or 3 but sparing the palm and dorsum of the hand (digit 1 is the thumb; digit 5 is the little finger); the “probable” pattern is similar to the classic pattern, although palm symptoms are allowed; the “unlikely” pattern depicts symptoms not involving digits 1, 2, or 3.¹⁹ Palm symptoms are not part of the classic pattern because the palmar cutaneous branch of the median nerve does not travel through the carpal tunnel.²⁰

D. CLINICAL SIGNIFICANCE

I. DIAGNOSING CERVICAL RADICULOPATHY

EBM Box 64.1 presents the diagnostic accuracy of bedside examination for cervical radiculopathy as applied to patients presenting with neck pain, arm pain, or both. In these patients, the findings that *increase* the probability of radiculopathy the most are reduced biceps reflex (likelihood ratio [LR] = 9.1, see **EBM Box 64.1**), a positive Spurling test (LR = 4.5), and reduction of any arm reflex (i.e., biceps, brachioradialis, or triceps reflex, LR = 3.6). Findings that *decrease* probability of radiculopathy are normal rotation of the neck (i.e., can rotate to affected side >60 degrees, LR = 0.2) and the absence of arm muscle weakness (LR = 0.4).

Despite its modest accuracy, however, the Spurling test should probably *not* be performed. In other studies of cervical radiculopathy, its sensitivity is only 9% to 16%,^{25,26} and in patients with rheumatoid arthritis, cervical malformations, or metastatic disease, the test risks serious injury to the spine.

2. LOCALIZING CERVICAL RADICULOPATHY

EBM Box 64.2 presents the diagnostic accuracy of the motor, sensory, and reflex examination in patients with known cervical radiculopathy, illustrating the accuracy of findings in predicting the exact level of the lesion. According to these LRs, the best indicator of C5 radiculopathy is weak elbow flexion (LR = 5.3). A diminished biceps or brachioradialis reflex (LR = 14.2), sensory loss affecting the thumb (LR = 8.5), and weak wrist extension (LR 2.3) indicate C6 radiculopathy. Weak elbow extension (LR = 4) and a diminished triceps reflex (LR = 3) indicate C7 radiculopathy, whereas normal elbow extensor strength modestly decreases the probability for this diagnosis (LR = 0.4). Sensory loss affecting the little finger (LR = 41.4) and weak finger flexion (LR = 3.8) indicate C8 radiculopathy.

These LRs show that each of the indicator muscles discussed in **Chapter 61** (i.e., elbow flexion for C5, wrist extension for C6, elbow extension for C7, and finger flexion for C8) predict the level involved (LRs = 2.3 to 5.3). The weaker a muscle is, the more significant its localizing value.⁵ Also, although certain sensory findings



EBM BOX 64. I

*Diagnosing Cervical Radiculopathy in Patients With Neck and Arm Pain**

Finding (Reference) [†]	Sensitivity (%)	Specificity (%)	Likelihood Ratio‡	
			Present	Absent
Motor Examination				
Weakness of any arm muscle ⁶	73	61	1.9	0.4
Sensory Examination				
Reduced vibration or pin-prick sensation in arm ⁶	38	46	NS	NS
Reflex Examination				
Reduced biceps reflex ⁶	10	99	9.1	NS
Reduced brachioradialis reflex ⁶	8	99	NS	NS
Reduced triceps reflex ⁶	10	95	NS	NS
Reduced biceps, triceps, or brachioradialis reflex ⁶	21	94	3.6	0.8
Other Tests				
Spurling test ^{7,21-24}	12-92	84-98	4.5	0.6
Rotation of neck to involved side <60 degrees ⁷	89	48	1.7	0.2

*Diagnostic standard: For cervical radiculopathy, nerve conduction studies,^{7,21} neuroimaging (computed tomography or magnetic resonance imaging),^{23,24} or MRI and surgery.²²

[†]Definition of findings: For Spurling test, see text.

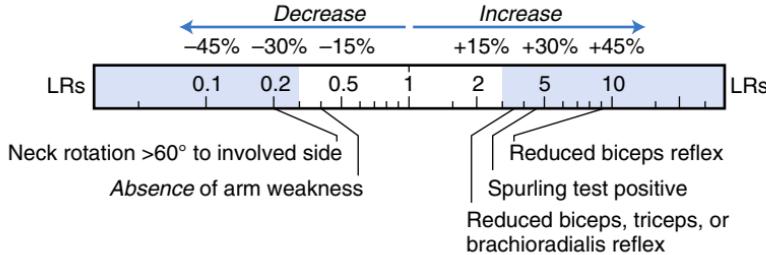
[‡]Likelihood ratio (LR) if finding present = positive LR; LR if finding absent = negative LR.

NS, Not significant.

[Click here to access calculator](#)

CERVICAL RADICULOPATHY (IF NECK AND ARM PAIN)

Probability





EBM BOX 64.2

Localizing Cervical Radiculopathy*

Finding (Reference)	Sensitivity (%)	Specificity (%)	Likelihood Ratio [†] if Finding Is	
			Present	Absent
Motor Examination				
Weak elbow flexion, detecting C5 radiculopathy ⁵	83	84	5.3	NS
Weak wrist extension, detecting C6 radiculopathy ⁵	37	84	2.3	NS
Weak elbow extension, detecting C7 radiculopathy ⁵	65	84	4.0	0.4
Weak finger flexion, detecting C8 radiculopathy ⁵	50	87	3.8	NS
Sensory Examination				
Sensory loss affecting thumb, detecting C6 radiculopathy ⁵	32	96	8.5	NS
Sensory loss affecting middle finger, detecting C7 radiculopathy ⁵	5	98	NS	NS
Sensory loss affecting little finger, detecting C8 radiculopathy ⁵	23	99	41.4	NS
Reflex Examination				
Diminished biceps or brachioradialis reflex, detecting C6 radiculopathy ⁵	53	96	14.2	0.5
Diminished triceps reflex, detecting C7 radiculopathy ^{5,6}	15-65	81-93	3.0	NS

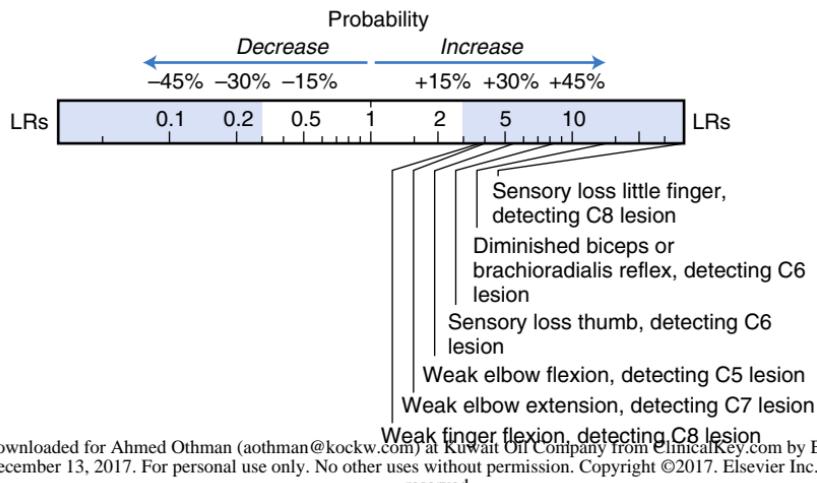
*Diagnostic standard: For level of radiculopathy, surgical findings⁵ or electrodiagnosis.⁶

[†]Likelihood ratio (LR) if finding present = positive LR; LR if finding absent = negative LR.

NS, Not significant.

[Click here to access calculator](#)

LOCALIZING CERVICAL RADICULOPATHY



are diagnostic (e.g., sensory loss affecting the little finger of C8 radiculopathy, LR = 41.4), fewer than one in three patients with cervical radiculopathy has any sensory loss; therefore the finding of *normal* sensation is never a compelling argument against cervical radiculopathy (i.e., negative LRs for all sensory findings are not significant).

Importantly, the LRs in **EBM Box 64.2** apply only to patients with cervical radiculopathy. Patients with carpal tunnel syndrome may also develop hypesthesia of the thumb, and those with ulnar neuropathy may develop hypesthesia of the little finger, although in these patients, the arm reflexes and arm and wrist strength are normal.

3. PLEXOPATHY IN CANCER PATIENTS

If brachial plexopathy develops in a patient with cancer who has received radiation near the shoulder, the question arises whether the plexopathy is due to metastatic disease or radiation injury. Findings increasing the probability of *metastatic* involvement are motor and sensory findings confined to C7-T1 (LR = 30.9) and Horner syndrome (LR = 4.1). Findings increasing the probability of *radiation* injury are motor and sensory findings confined to C5-C6 (LR = 8.8) and lymphedema of the ipsilateral arm (LR = 4.9).²⁷

4. PERIPHERAL NERVE INJURY: DIAGNOSIS OF CARPAL TUNNEL SYNDROME

EBM Box 64.3 summarizes the diagnostic accuracy of findings for the most common peripheral neuropathy of the arm, carpal tunnel syndrome. According to this EBM Box, three findings modestly increase the probability of carpal tunnel syndrome: diminished pain sensation in the distribution of the median nerve (LR = 3.1), a square wrist ratio (defined in footnote of **EBM Box 64.3**, LR = 2.7), and a “classic” or “probable” hand diagram (LR = 2.4; see **Fig. 64.5**). The finding *decreasing* probability of carpal tunnel syndrome the most is an “unlikely” hand diagram (LR = 0.2). Several traditional tests—such as the Tinel sign and Phalen sign and other novel ones such as the pressure provocation and flick signs (defined in a footnote in **EBM Box 64.3**)—do not distinguish carpal tunnel syndrome from other common disorders that cause hand dysesthesias (such as polyneuropathy, ulnar neuropathy, or radiculopathy, using electrodiagnosis as the diagnostic standard).^{1,43}



EBM BOX 64.3

*Diagnosing Carpal Tunnel Syndrome**

Finding (Reference) [†]	Sensitivity (%)	Specificity (%)	Likelihood Ratio [‡] if Finding Is	
			Present	Absent
Hand Diagram				
“Classic” or “probable” ¹⁹	64	73	2.4	0.5
“Unlikely” ¹⁹	4	77	0.2	—
Motor Examination				
Weak thumb abduction ²⁸⁻³⁰	37-66	62-74	1.8	0.5
Thenar atrophy ²⁹⁻³²	4-28	82-99	1.7	NS

Continued

**EBM BOX 64.3***Diagnosing Carpal Tunnel Syndrome**—cont'd

Finding (Reference) [†]	Sensitivity (%)	Specificity (%)	Likelihood Ratio [‡] if Finding Is	
			Present	Absent
Sensory Examination (Median Distribution)				
Hypalgesia ^{28,31}	15-51	85-93	3.1	NS
Diminished two-point discrimination ^{29,32,33}	6-32	64-99	NS	NS
Abnormal vibration sensation ^{29,33}	20-61	71-81	NS	NS
Diminished monofilament sensation ^{33,34}	59-98	15-59	NS	NS
Other Tests				
Tinel sign ^{28-33,35,36}	23-60	56-91	1.4	NS
Phalen sign ^{28-33,35-39}	10-91	33-86	1.3	0.7
Pressure provocation test ^{28,30,33,37,38,40}	28-77	17-74	NS	NS
Square wrist ratio ^{28, 41}	47-69	73-83	2.7	0.5
Flick sign ^{36,42}	37-93	74-96	NS	NS

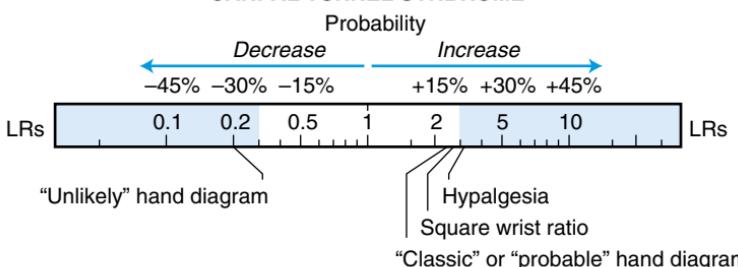
*Diagnostic standard: For carpal tunnel syndrome, abnormal motor or sensory conduction within the carpal tunnel, measured by nerve conduction testing.

[†]Definition of findings: For hand diagram, see Fig. 64.5; for all sensory findings, perception diminished in index finger compared with ipsilateral little finger (two-point discrimination used compass points separated by 4 to 6 mm, vibratory sensation used 126- or 256-Hz tuning fork, monofilament sensation abnormal if > 2.83); for Tinel sign, Phalen sign, and pressure provocation test, the positive response is paresthesias in the distribution of the median nerve, although each test uses a different stimulus—tapping on the distal wrist crease over the median nerve (Tinel sign), maximal wrist flexion for 60 seconds (Phalen sign), and firm pressure with examiner's thumbs on palmar aspect of patient's distal wrist crease for 60 seconds (pressure provocation test);⁴³ for square wrist ratio, anteroposterior dimension of wrist divided by mediolateral dimension, measured with calipers at distal wrist crease, is ≥0.7;⁸⁵ and for Flick sign, the patient is asked, "What do you actually do with your hand(s) when the symptoms are at their worst?" and in reply the patient demonstrates a flicking movement of the wrist and hand, similar to that employed in shaking down a thermometer.⁴²

[‡]Likelihood ratio (LR) if finding present = positive LR; LR if finding absent = negative LR.

NS, Not significant.

[Click here to access calculator](#)

CARPAL TUNNEL SYNDROME

III. THE LEG

A. INTRODUCTION

Among patients who present with nerve complaints affecting the lower extremity, the most common neurologic diagnosis by far is lumbosacral radiculopathy, which usually affects the L5 or S1 roots (each is affected with about the same frequency).^{4,44-49}

B. NEUROLOGIC FINDINGS

I. MOTOR

Fig. 64.6 presents the innervation of the muscles of the leg, showing the relationship between different spinal roots (arranged in columns) and the different peripheral nerves (grouped in rows).

A. RADICULOPATHY

Like radiculopathy of the arm, radiculopathy of the leg has two characteristics: (1) Weakness affects two or more muscles from the same spinal segment but different peripheral nerves (i.e., all muscles innervated by same column in Fig. 64.6). For example, an L5 radiculopathy may affect both the dorsiflexors of the foot and toes (peroneal nerve) and inversion of the foot (tibial nerve). (2) Weakness may involve *proximal nerves* to the glutei muscles, producing characteristic weakness

SPINAL SEGMENTS	L2	L3	L4	L5	S1	S2
Proximal nerves						
Gluteus medius (gluteal nerves; internal rotation and abduction of hips)				dark blue shade	dark blue shade	
Gluteus maximus (gluteal nerves; extension of hips)					dark blue shade	dark blue shade
Femoral nerve						
Iliopsoas	dark blue shade	dark blue shade				
Quadriceps	dark blue shade	dark blue shade	dark blue shade			
Obturator nerve						
Thigh adductors	dark blue shade	dark blue shade	dark blue shade			
Sciatic nerve trunk*					dark blue shade	dark blue shade
Hamstrings (knee flexion)					dark blue shade	dark blue shade
Peroneal nerve*						
Tibialis anterior (dorsiflexion of ankle)				dark blue shade	dark blue shade	
Extensors of toes					dark blue shade	
Peroneal longus (eversion of ankle)					dark blue shade	dark blue shade
Tibial nerve*						
Tibialis posterior (inversion of ankle)				dark blue shade	dark blue shade	
Gastrocnemius					dark blue shade	
Flexor digitorum (curl toes)					dark blue shade	dark blue shade

FIG. 64.6 INNERVATION OF THE MUSCLES OF THE LEG. This figure indicates those spinal levels that usually (dark blue shade) and sometimes (light blue shade) contribute to the corresponding muscle.^{4,8,9,12,14,50,51} The sciatic nerve trunk divides above the knee into the peroneal and tibial nerves; therefore lesions of the sciatic nerve trunk affect the muscles of all three branches (indicated by the asterisk in the figure; see text).

and gait abnormalities (i.e., gluteus maximus gait and Trendelenburg gait; see Chapter 7).

B. LUMBOSACRAL PLEXOPATHY

Unlike brachial plexus lesions, lumbosacral plexopathies tend to affect the entire leg (L2-S1) simultaneously; discrete upper and lower plexus syndromes are rare.^{52,53}

C. PERIPHERAL NERVE DISORDERS

Peripheral nerve lesions weaken two or more muscles from a *single* peripheral nerve (which may belong to different spinal segments) and spare muscles from other nerves. For example, over 85% of patients with foot drop due to peroneal nerve injury have weak ankle dorsiflexion (L4-L5) and eversion (L5-S1) but preservation of inversion (i.e., same spinal segments but different nerve, the tibial nerve).⁵⁴

The sciatic trunk divides into the peroneal and tibial nerves just above the knee. Lesions of the sciatic trunk may therefore affect any of the muscles listed under sciatic trunk, peroneal nerve, and tibial nerve in Fig. 64.6. Most patients with sciatic neuropathy have either greater involvement of the peroneal division (75% of patients) or equal involvement of the peroneal and tibial divisions (20% of patients). A sciatic neuropathy with greater involvement of the tibial nerve muscles is uncommon.⁵⁵

The finding of weakness predominantly of the proximal leg muscles is unlikely in sciatic, peroneal, or tibial neuropathy because all of these nerves innervate muscles below the knee. Therefore proximal weakness suggests femoral or obturator neuropathy, lumbosacral plexopathy or radiculopathy, or, if sensory findings are absent, muscle disease.

2. SENSORY FINDINGS

Radiculopathy causes sensory loss in a dermatomal pattern (see Table 62.1 and Fig. 62.1 in Chapter 62); peripheral nerve lesions cause the sensory loss described in Fig. 64.7; and lumbosacral plexopathies tend to affect the entire leg.

A pure sensory syndrome is **meralgia paresthetica**, which consists of hypesthesia of the anterior and lateral thigh, usually caused by mechanical compression of the lateral femoral cutaneous nerve (e.g., obesity, pregnancy, or a carpenter's belt).⁵⁶

3. REFLEXES

The two muscle stretch reflexes of the leg are the quadriceps reflex (femoral nerve, L2- L4) and Achilles reflex (tibial nerve, S1). The peroneal nerve does not contribute to the Achilles reflex. Consequently, in patients with foot drop, the finding of an asymmetrically diminished or absent ankle jerk *decreases* probability of peroneal palsy and *increases* probability of sciatic neuropathy (87% have an abnormal ankle jerk)⁵⁵ or lumbosacral radiculopathy (14% to 48% have an abnormal ankle jerk).^{12,44,48,57,58}

4. PROVOCATIVE TESTS

The **straight leg raising** test is a traditional maneuver used to diagnose lumbosacral radiculopathy, which is usually caused by disc herniation. In the maneuver, the clinician lifts the extended leg of the supine patient, flexing the leg at the hip. In a positive response, the patient develops pain down the ipsilateral leg (if pain develops just in the hip or back, the test is considered negative). The **crossed straight leg raising** maneuver consists of pain in the affected leg when the clinician lifts the contralateral healthy limb. The pathogenesis of the sign is believed to be stretching of the sciatic nerve and its nerve roots.⁵⁹

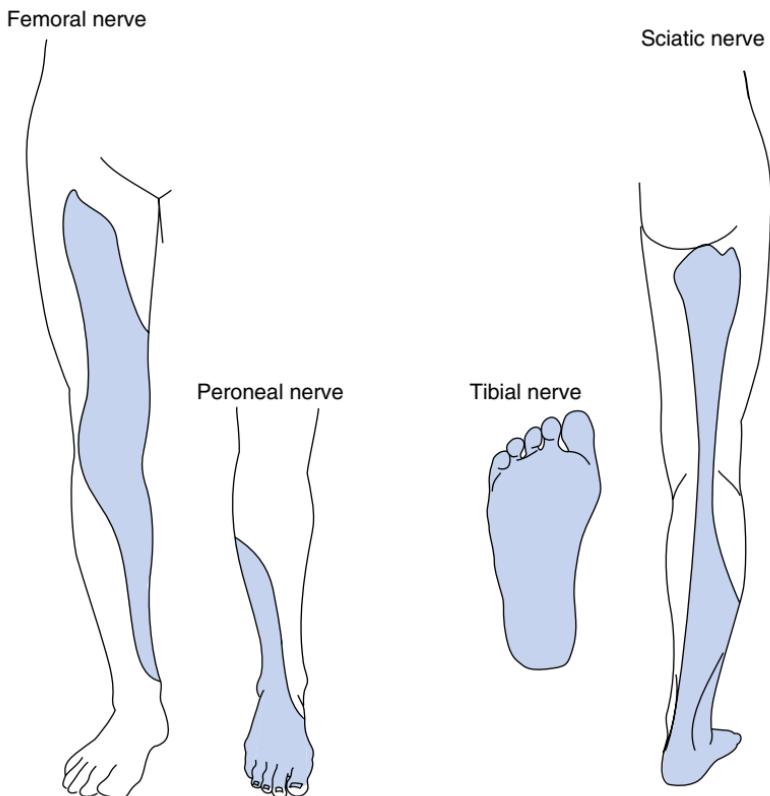


FIG. 64.7 SENSORY BRANCHES OF THE PERIPHERAL NERVES OF THE LEG. The two figures on the left depict the front surface of the leg; the two on the right, the sole of the foot and back of the leg. The sciatic nerve trunk divides above the knee into the peroneal and tibial nerves; therefore, lesions of the sciatic nerve trunk affect sensation from all three branches (i.e., posterior thigh, posterior cutaneous nerve of the thigh; lateral calf and top of foot, peroneal nerve; and sole of foot, tibial nerve).

A positive straight leg raising test is sometimes called the **Lasègue sign**, after the French clinician Charles Lasègue (1816–1883), although Lasègue never published a description of the sign. His student Forst described the maneuver in his 1881 doctoral thesis, crediting Lasègue. An earlier description of the sign was published by Yugoslavian physician Lazarevic in 1880.⁶⁰⁻⁶²

The **femoral nerve stretch test** was designed to confirm an upper lumbar radiculopathy (i.e., L2 to L4 roots). In this test, the patient is positioned prone and the clinician passively flexes the knee of the patient's affected limb. The positive response is pain in the patient's back and anterior thigh, presumably from stretching of the irritated upper lumbar roots.^{63,64}

C. CLINICAL SIGNIFICANCE

I. LUMBOSACRAL RADICULOPATHY

EBM Boxes 64.4 and 64.5 review the diagnostic accuracy of the bedside examination in patients with nerve pain in one leg (i.e., sciatica). EBM Box 64.4 applies

**EBM BOX 64.4****Diagnosing Lumbosacral Radiculopathy in Patients With Sciatica***

Finding (Reference) [†]	Sensitivity (%)	Specificity (%)	Likelihood Ratio [‡] if Finding Is	
			Present	Absent
Motor Examination				
Weak ankle dorsiflexion ⁴⁸	54	89	4.9	0.5
Ipsilateral calf wasting ⁴⁸	29	94	5.2	0.8
Sensory Examination				
Leg sensation abnormal ^{48,57,58,65}	16-50	62-86	NS	NS
Reflex Examination				
Abnormal ankle jerk ^{48,57,58,65}	14-48	73-93	2.1	0.8
Other Tests				
Straight leg raising maneuver ^{45,48,58,65-69}	53-98	11-89	1.5	0.4
Crossed straight leg raising maneuver ^{48,66-68,70}	22-43	88-98	3.4	0.8

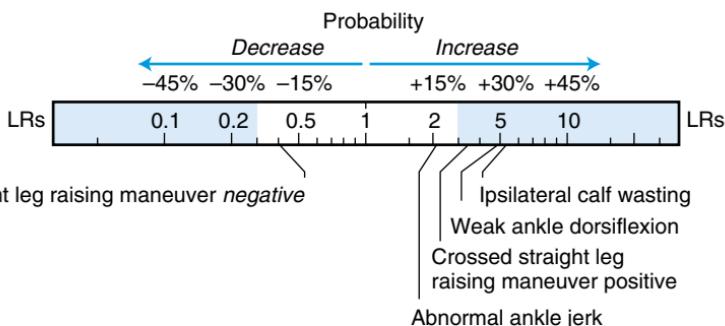
*Diagnostic standard: For lumbosacral radiculopathy, surgical findings,^{45,48,66,67} electrodiagnosis,⁵⁷ magnetic resonance imaging or computed tomography^{58,65,68,69} indicating lumbosacral nerve root compression.

[†]Definition of findings: For ipsilateral calf wasting, maximum calf circumference at least 1 cm smaller than contralateral side;⁴⁸ for straight leg raising maneuvers, flexion at hip of supine patient's leg, extended at the knee, causes radiating pain in affected leg (pain confined to back or hip is negative response); for crossed straight leg raising maneuver, raising contralateral leg provokes pain in affected leg.

[‡]Likelihood ratio (LR) if finding present = positive LR; LR if finding absent = negative LR.

NS, Not significant.

[Click here to access calculator](#)

LUMBOSACRAL RADICULOPATHY



EBM BOX 64.5

Localizing Lumbosacral Radiculopathy*

Finding (Reference) [†]	Sensitivity (%)	Specificity (%)	Likelihood Ratio [‡] if Finding Is	
			Present	Absent
Motor Examination				
Weak knee extension, detecting L3 or L4 radiculopathy ^{57,63,71}	38-48	89-90	4.0	0.6
Weak hallux extension, detecting L5 radiculopathy ^{44,48,57,63}	12-62	54-91	1.7	0.7
Weak ankle dorsiflexion, detecting L5 radiculopathy ^{48,72}	37-62	51-77	NS	NS
Weak ankle plantarflexion, detecting S1 radiculopathy ^{48,57}	26-45	75-99	NS	0.7
Ipsilateral calf wasting, detecting S1 radiculopathy ⁴⁸	43	82	2.4	0.7
Sensory Examination				
Sensory loss in L5 distribution, detecting L5 radiculopathy ^{44,48,72}	20-53	77-98	3.1	0.8
Sensory loss in S1 distribution, detecting S1 radiculopathy ^{44,48,72}	32-49	70-90	2.4	0.7
Reflex Examination				
Asymmetric quadriceps reflex, detecting L3 or L4 radiculopathy ^{44,57,63,73}	29-56	93-96	8.5	0.7
Asymmetric medial hamstring reflex, detecting L5 radiculopathy ⁷⁴	57	91	6.2	0.5
Asymmetric Achilles reflex, detecting S1 radiculopathy ^{44,48,57,72,73,75}	45-91	53-94	2.7	0.5
Other Tests				
Femoral stretch test, detecting L2-L4 radiculopathy ⁶³	52	98	31.2	0.5

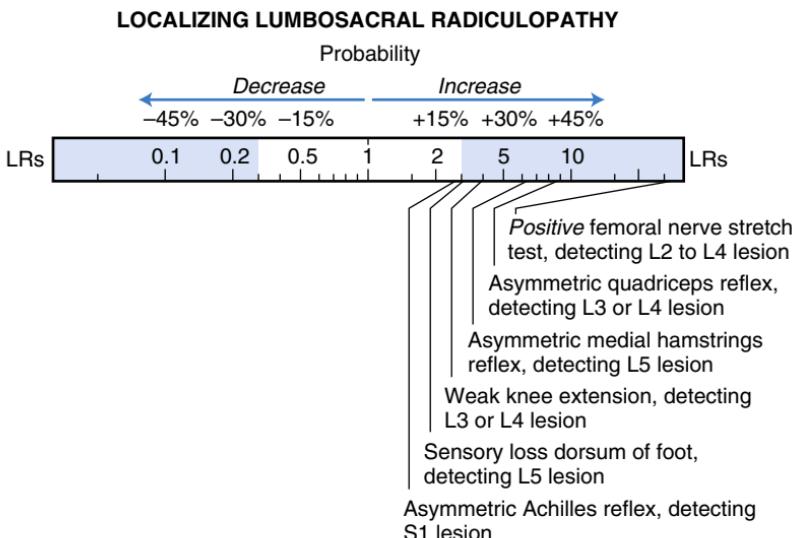
*Diagnostic standard: For level of radiculopathy, surgical findings and preoperative myelography, ^{44,48,72,73,75} magnetic resonance imaging, ^{63,71} or electrodiagnosis. ⁵⁷

[†]Definition of findings: For weak knee extension, manual muscle testing^{57,71} or the sit-to-stand test (with the clinician holding the seated patient's hands as a balance aid only), the patient is unable to stand using the affected leg;⁶³ for ipsilateral calf wasting, maximum calf circumference at least 1 cm smaller than contralateral side.⁴⁸

[‡]Likelihood ratio (LR) if finding present = positive LR; LR if finding absent = negative LR. NS, Not significant.

[Click here to access calculator](#)

Continued



to all patients with sciatica. **EBM Box 64.5** applies only to patients with known lumbosacral radiculopathy and addresses how accurately findings localize the level of the lesion.

In patients with sciatica, the findings that *increase* the probability of disc herniation and lumbosacral radiculopathy[‡] are calf wasting (LR = 5.2), weak ankle dorsiflexion (LR = 4.9), the crossed straight leg raising maneuver (LR = 3.4), and the absent ankle jerk (LR = 2.1). A *negative* straight leg raising maneuver modestly *decreases* the probability of disc herniation (LR = 0.4).

Some clinicians propose performing the straight leg raising maneuver in the seated patient whose hip is already flexed at 90 degrees; the maneuver then consists of simply extending the knee. Two studies,^{76,77} however, have demonstrated that this maneuver has diminished sensitivity compared with the traditional maneuver performed with the patient supine.

In patients with sciatica and lumbosacral radiculopathy (**EBM Box 64.5**), an abnormal quadriceps reflex (LR = 8.5) or weak knee extension (LR = 4) points to the L3 or L4 level. A positive femoral stretch test also localizes the lesion to the upper lumbar level (L2 to L4; LR = 31.2). The best test for L5 radiculopathy is an asymmetric medial hamstring reflex (LR = 6.2) or L5 sensory loss (dorsum of the foot; LR = 3.1). The best predictors for the S1 level are sensory loss in the S1 distribution (lateral heel, LR = 2.4), reduced Achilles reflex (LR = 2.7), and ipsilateral calf wasting (LR = 2.4).

As discussed earlier, the finding of *proximal* muscle weakness (top row of **Fig. 64.6**) in a patient with distal limb symptoms convincingly argues for radiculopathy and against peripheral neuropathy. As an example, in one study of patients with foot drop from various causes, the finding of ipsilateral hip abductor weakness (i.e., gluteus medius weakness) accurately detected lumbosacral radiculopathy (sensitivity = 86%; specificity = 96%; positive LR = 24; negative LR = 0.1).⁷⁸

[‡]An L4-L5 disc compresses the L5 root and an L5-S1 disc compresses the S1 root.

2. LUMBOSACRAL PLEXOPATHY

A. CANCER PATIENTS

In patients with known cancer and prior pelvic irradiation who present with lumbosacral plexopathy, findings confined to one leg increase probability of *recurrent tumor* (LR = 4.5), whereas findings in both legs increase probability of *radiation plexopathy* (LR = 7.5).⁵²

B. DIABETIC AMYOTROPHY⁷⁹⁻⁸³

Diabetic amyotrophy (or diabetic proximal neuropathy) is a lumbosacral plexopathy of diabetic patients with presenting symptoms of weak thigh muscles and severe pain in the thighs, back, or both. The quadriceps, adductor, and iliopsoas muscles are weak 100% of the time and the glutei and hamstrings 50% of the time (all are proximal muscles). The weakness may be unilateral or bilateral, but it is always asymmetric. Sensation is normal (70% of the time) or diminished over the thigh (30% of the time). The quadriceps reflex is absent in 80% of patients.

Although patients with diabetes also develop femoral neuropathy,⁸⁴ this affects only thigh flexion and knee extension and spares other proximal leg muscles.

The references for this chapter can be found on www.expertconsult.com.

This page intentionally left blank

REFERENCES

1. Haig AJ, Tzeng HM, LeBreck D. The value of electrodiagnosis consultation for patients with upper extremity nerve complaints: a prospective comparison with the history and physical examination. *Arch Phys Med Rehabil.* 1999;80:1273–1281.
2. Kothari MJ, Blakeslee MA, Reichwein R, Simmons Z, Logigian EL. Electrodiagnostic studies: are they useful in clinical practice. *Arch Phys Med Rehabil.* 1998;79:1510–1511.
3. Wainner RS, Fritz JM, Irrgang JJ, Delitto A, Allison S, Boninger ML. Development of a clinical prediction rule for the diagnosis of carpal tunnel syndrome. *Arch Phys Med Rehabil.* 2005;86:609–618.
4. Wilbourn AJ, Aminoff MJ. AAEM minimonograph 32: the electrodiagnostic examination in patients with radiculopathies. *Muscle Nerve.* 1998;21:1612–1631.
5. Yoss RE, Corbin KB, MacCarty CS, Love JG. Significance of symptoms and signs in localization of involved root in cervical disk protrusion. *Neurology.* 1957;7(10):673–683.
6. Lauder TD, Dillingham TR, Andary M, et al. Predicting electrodiagnostic outcome in patients with upper limb symptoms: are the history and physical examination helpful? *Arch Phys Med Rehabil.* 2000;81:436–441.
7. Wainner RS, Fritz JM, Irrgang JJ, Boninger ML, Delitto A, Allison S. Reliability and diagnostic accuracy of the clinical examination and patient self-report measures for cervical radiculopathy. *Spine.* 2003;28(1):52–63.
8. Nieuwenhuys R. Bolk's studies of segmental anatomy. *Acta Morphol Neerl Scand.* 1975;13:7–33.
9. Wolf JK. *Segmental Neurology: A Guide to the Examination and Interpretation of Sensory and Motor Function.* Baltimore, MD: University Park Press; 1981.
10. Brendler SJ. The human cervical myotomes: functional anatomy studied at operation. *J Neurosurg.* 1968;28:105–111.
11. Levin KH, Maggiano HJ, Wilbourn AJ. Cervical radiculopathies: comparison of surgical and EMG localization of single-root lesions. *Neurology.* 1996;46:1022–1025.
12. Young JH. The revision of the dermatomes. *Aust N Z J Surg.* 1949;18(3):171–186.
13. Makin GJV, Brown WF, Ebers GC. C7 radiculopathy: importance of scapular winging in clinical diagnosis. *J Neurol Neurosurg Psychiatry.* 1986;49:640–644.
14. The Guarantors of Brain. *Aids to the Examination of the Peripheral Nervous System.* 5th ed. Edinburgh: Saunders Elsevier; 2010.
15. Reid RI, Ashby MA. Ulnar nerve palsy and walking frames. *Br Med J.* 1982;285:778.
16. Maimaris C, Zadeh HG. Ulnar nerve compression in the cyclist's hand: two case reports and review of the literature. *Br J Sports Med.* 1990;24(4):245–246.
17. Massey EW, Pleet AB. Handcuffs and cheiralgia paresthetica. *Neurology.* 1978;28:1312–1313.
18. Spurling RG, Scoville WB. Lateral rupture of the cervical intervertebral discs: a common cause of shoulder and arm pain. *Surg Gynecol Obstet.* 1944;78:350–358.
19. Katz JN, Stirrat C, Larson MG, Eaton HM, Liang MH. A self-administered hand symptom diagram in the diagnosis and epidemiologic study of carpal tunnel syndrome. *J Rheumatol.* 1990;17:1495–1498.
20. Lum PB, Kanaklamedala R. Conduction of the palmar cutaneous branch of the median nerve. *Arch Phys Med Rehabil.* 1986;67:805–806.
21. Tong HC, Haig AJ, Yamakawa K. The Spurling test and cervical radiculopathy. *Spine.* 2002;27(2):156–159.
22. Shah KC, Rajshekhar V. Reliability of diagnosis of soft cervical disc prolapse using Spurling's test. *Br J Neurosurg.* 2004;18(5):480–483.
23. Uchihara T, Furukawa T, Tsukagoshi H. Compression of brachial plexus as a diagnostic test of cervical core lesion. *Spine.* 1994;19(19):2170–2173.
24. Shabat S, Leitner Y, David R, Folman Y. The correlation between Spurling test and imaging studies in detecting cervical radiculopathy. *J Neuroimaging.* 2012;22:375–378.
25. Viikari-Juntura E, Porras M, Laasonen EM. Validity of clinical tests in the diagnosis of root compression in cervical disc disease. *Spine.* 1989;14(3):253–257.
26. Lunsford LD, Bissonette DJ, Jannetta PJ, Sheptak PE, Zolrub DS. Anterior surgery for cervical disc disease. Part 1: treatment of lateral cervical disc herniation in 253 cases. *J Neurosurg.* 1980;53:1–11.

27. Kori SH, Foley KM, Posner JB. Brachial plexus lesions in patients with cancer: 100 cases. *Neurology*. 1981;31:45–50.
28. Kuhlman KA, Hennessey WJ. Sensitivity and specificity of carpal tunnel syndrome signs. *Am J Phys Med Rehabil*. 1997;76:451–457.
29. Gerr F, Letz R. The sensitivity and specificity of tests for carpal tunnel syndrome vary with the comparison subjects. *J Hand Surg (Br)*. 1998;23B(2):151–155.
30. Makanji HS, Becker SJ, Mudgal CS, Jupiter JB, Ring D. Evaluation of the scratch collapse test for the diagnosis of carpal tunnel syndrome. *J Hand Surg Eur Vol*. 2014;39:181–186.
31. Golding DH, Rose DM, Selvarajah K. Clinical tests for carpal tunnel syndrome: an evaluation. *Br J Rheumatol*. 1986;25:388–390.
32. Katz JN, Larson MG, Sabra A, et al. Carpal tunnel syndrome: diagnostic utility of history and physical examination findings. *Ann Intern Med*. 1990;112:321–327.
33. Buch-Jaeger N, Foucher G. Correlation of clinical signs with nerve conduction tests in the diagnosis of carpal tunnel syndrome. *J Hand Surg (Br)*. 1994;19B:720–724.
34. Pagel KJ, Kaul MP, Dryden JD. Lack of utility of Semmes-Weinstein monofilament testing in suspected carpal tunnel syndrome. *Am J Phys Med Rehabil*. 2002;81(8):597–600.
35. Heller L, Ring H, Costeff H, Solzi P. Evaluation of Tinel's and Phalen's signs in the diagnosis of the carpal tunnel syndrome. *Eur Neurol*. 1986;25:40–42.
36. Hansen PA, Micklesen P, Robinson LR. Clinical utility of the flick maneuver in diagnosing carpal tunnel syndrome. *Am J Phys Med Rehabil*. 2004;83:363–367.
37. Burke DT, Burke MAM, Bell R, Stewart GW, Mehdi RS, Kim HJ. Subjective swelling: a new sign for carpal tunnel syndrome. *Am J Phys Med Rehabil*. 1999;78:504–508.
38. DeSmet L, Steenwerckx A, van den Bogaert G, Cnudde P, Fabry G. Value of clinical provocative tests in carpal tunnel syndrome. *Acta Orthop Belg*. 1995;61:177–182.
39. Boland RA, Kieran MC. Assessing the accuracy of a combination of clinical tests for identifying carpal tunnel syndrome. *J Clin Neurosci*. 2009;16:929–933.
40. Kaul MP, Pagel KJ, Wheatley MJ, Dryden JD. Carpal compression test and pressure provocative test in veterans with median-distribution paresthesias. *Muscle Nerve*. 2001;24:107–111.
41. Radecki P. A gender specific wrist ratio and the likelihood of a median nerve abnormality at the carpal tunnel. *Am J Phys Med Rehabil*. 1988;67:157–162.
42. Pryse-Phillips WEM. Validation of a diagnostic sign in carpal tunnel syndrome. *J Neurol Neurosurg Psychiatry*. 1984;47:870–872.
43. D'Arcy C, McGee S. Does this patient have carpal tunnel syndrome? *J Am Med Assoc*. 2000;283(23):3110–3117.
44. Kortelainen P, Puranen J, Koivisto E, Laehde S. Symptoms and signs of sciatica and their relation to the localization of the lumbar disc herniation. *Spine*. 1985;10(1):88–92.
45. Kosteljanetz M, Esperen JO, Halaburt H, Miletic T. Predictive value of clinical and surgical findings in patients with lumbago-sciatica; a prospective study (Part 1). *Acta Neurochir*. 1984;73:67–76.
46. Jonsson B, Stromqvist B. Symptoms and signs in degeneration of the lumbar spine: a prospective, consecutive study of 300 operated patients. *J Bone Joint Surg (Br)*. 1993;75-B:381–385.
47. Supik LF, Broom MJ. Sciatic tension signs and lumbar disc herniation. *Spine*. 1994;19(9):1066–1069.
48. Kerr RSC, Cadoux-Hudson TA, Adams CBT. The value of accurate clinical assessment in the surgical management of the lumbar disc protrusion. *J Neurol Neurosurg Psychiatry*. 1988;51:169–173.
49. Hakelius A, Hindmarsh J. The comparative reliability of preoperative diagnostic methods in lumbar disc surgery. *Acta Orthop Scand*. 1972;43:234–238.
50. Liguori R, Krarup C, Trojaborg W. Determination of the segmental sensory and motor innervation of lumbosacral spinal nerves. *Brain*. 1992;115:915–934.
51. Thage O. The myotomes L2-S2 in man. *Acta Neurol Scand*. 1965;41(suppl 13):241–243.
52. Thomas JE, Cascino TL, Earle JD. Differential diagnosis between radiation and tumor plexopathy of the pelvis. *Neurology*. 1985;35:1–7.
53. Pettigrew LC, Glass JP, Maor M, Zornoza J. Diagnosis and treatment of lumbosacral plexopathies in patients with cancer. *Arch Neurol*. 1984;41:1282–1285.
54. Katirji MB, Wilbourn AJ. Common peroneal mononeuropathy: a clinical and electro-physiologic study of 116 lesions. *Neurology*. 1988;38:1723–1728.

55. Yuen EC, Olney RK, So YT. Sciatic neuropathy: clinical and prognostic features in 73 patients. *Neurology*. 1994;44:1669–1674.
56. Massey EW. Sensory mononeuropathies. *Semin Neurol*. 1998;18(2):177–183.
57. Lauder TD, Dillingham TR, Andary M, et al. Effect of history and exam in predicting electrodiagnostic outcome among patients with suspected lumbosacral radiculopathy. *Am J Phys Med Rehabil*. 2000;79(1):60–68.
58. Vroomen PCAJ, De Krom MCTFM, Knottnerus JA. Consistency of history taking and physical examination in patients with suspected lumbar nerve root involvement. *Spine*. 2000;25(1):91–97.
59. Goddard MD, Reid JD. Movements induced by straight leg raising in the lumbo-sacral roots, nerves and plexus, and in the intrapelvic section of the sciatic nerve. *J Neurol Neurosurg Psychiatry*. 1965;28:12–18.
60. Pearce JMS. Lasegue's sign. *Lancet*. 1989;1:436.
61. Sugar O. Charles Lasegue and his "considerations on sciatica." *J Am Med Assoc*. 1985;253:1767–1768.
62. Dyck P. Lumbar nerve root: the enigmatic eponyms. *Spine*. 1984;9(1):3–5.
63. Suri P, Rainville J, Katz JN, et al. The accuracy of the physical examination for the diagnosis of midlumbar and low lumbar nerve root impingement. *Spine*. 2011;36:63–73.
64. De Luijli AJ, Fitzpatrick KF. Physical examination in radiculopathy. *Phys Med Rehabil Clin North Am*. 2011;22:7–40.
65. Coster S, de Brujin SF, Tavy DLJ. Diagnostic value of history, physical examination and needle electromyography in diagnosing lumbosacral radiculopathy. *J Neurol*. 2010;257:332–337.
66. Kosteljanetz M, Bang F, Schmidt-Olsen S. The clinical significance of straight-leg raising (Lasegue's sign) in the diagnosis of prolapsed lumbar disc: interobserver variation and correlation with surgical findings. *Spine*. 1988;13(4):393–395.
67. Spangfort EV. The lumbar disc herniation: a computer-aided analysis of 2504 operations. *Acta Orthop Scand Suppl*. 1972;142:1–95.
68. Poiradeau S, Foltz V, Drapé JL, et al. Value of the bell test and the hyperextension test for diagnosis in sciatica associated with disc herniation: comparison with Lasegue's sign and the crossed Lasegue's sign. *Rheumatology*. 2001;40:460–466.
69. Majlesi J, Togay H, Unalan H, Toprak S. The sensitivity and specificity of the slump and the straight leg raising tests in patients with lumbar disc herniation. *J Clin Rheumatol*. 2008;14:87–91.
70. Hudgins WB. The crossed straight leg raising test: a diagnostic sign of herniated disc. *J Occup Med*. 1979;21(6):407–408.
71. Rainville J, Jouve C, Finno M, Limke J. Comparison of four tests of quadriceps strength in L3 or L4 radiculopathies. *Spine*. 2003;28(21):2466–2471.
72. Jensen OH. The level-diagnosis of a lower lumbar disc herniation: the value of sensibility and motor testing. *Clin Rheumatol*. 1987;6(4):564–569.
73. Portnoy HD, Ahmad M. Value of the neurological examination, electromyography and myelography in herniated lumbar disc. *Mich Med*. 1972;71:429–434.
74. Jensen OH. The medial hamstring reflex in the level-diagnosis of a lumbar disc herniation. *Clin Rheumatol*. 1987;6(4):570–574.
75. Gurdjian ES, Webster JE, Ostowski AZ, Hardy WG, Lindner DW, Thomas LM. Herniated lumbar intervertebral discs—an analysis of 1176 operated cases. *J Trauma*. 1961;1:158–176.
76. Rabin A, Gerszte PC, Karausky P, Bunker CH, Potter DM, Welch WC. The sensitivity of the seated straight-leg raise test compared with the supine straight-leg test in patients presenting with magnetic resonance imaging evidence of lumbar nerve root compression. *Arch Phys Med Rehabil*. 2007;88:840–843.
77. Summers B, Mishra V, Jones JM. The flip test: a reappraisal. *Spine*. 2009;34(15):1585–1589.
78. Jeon CH, Chung NS, Lee YS, Son KH, Kim JH. Assessment of hip abductor power in patients with foot drop. *Spine*. 2013;38(3):257–263.
79. Subramony SH, Wilbourn AJ. Diabetic proximal neuropathy: clinical and electromyographic studies. *J Neurol Sci*. 1982;53:293–304.
80. Bastron JA, Thomas JE. Diabetic polyradiculopathy: clinical and electromyographic findings in 105 patients. *Mayo Clin Proc*. 1981;56:725–732.

612.e4 REFERENCES

81. Chokroverty S, Reyes MG, Rubino FA, Tonaki H. The syndrome of diabetic amyotrophy. *Ann Neurol.* 1977;2:181–194.
82. Asbury AK. Proximal diabetic neuropathy. *Ann Neurol.* 1977;2(3):179–180.
83. Sander HW, Chokroverty S. Diabetic amyotrophy: current concepts. *Sem Neurol.* 1996;16(2):173–178.
84. Fraser DM, Campbell IW, Ewing DJ, Clarke BF. Mononeuropathy in diabetes mellitus. *Diabetes.* 1979;28:96–101.
85. Johnson EW, Gatens T, Poindexter D, Bowers D. Wrist dimensions: correlation with median sensory latencies. *Arch Phys Med Rehabil.* 1983;64:556–557.